Distribution of Vibration of Chest Surface with Heart Movement

Fumio Nogata*[1], Yasunari Yokota[2], Yoko Kawamura[3]

*[1]Emeritus Professor/ Gifu University, Yanagi-do Gifu, 501-1193, Japan

[2,3]Department of Electrical, Electronic and Computer Engineering, Faculty of Engineering/ Gifu University, Yanagi-do Gifu, 501-1193, Japan

*[1]nogata@gifu-u.ac.jp; *[2]ykt@gifu-u.ac.jp; *[3]yokokawa@gifu-u.ac.jp

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Abstract

A technique for imaging distribution of chest's surface vibration due to heartbeat has been established. This technique is based on measurement of minute vibration of the chest surface using 64 sensors and image processing unit. Relations of the vibrational distribution and the heart motion were discussed. The results showed that vibration of the chest surface included three or four frequency bands; less than 50 Hz, 150-200 Hz, 500-600 Hz, and 700-800 Hz. Clear contour images of the heart were derived from vibration of less than 50 Hz band. And contour of contraction/expansion of atrioventricular and ventricle and location of valves were derived from whole frequency band. This method would be applicable to monitor the cardiac function for long time, e.g. to investigate some changes of the heart movement by abnormal heart rhythm on the basis of an electrocardiogram (ECG). We expected that the technique would assist much better understanding of heart function visually.

Keywords

Multichannel Sensing; Chest Vibration; Image Processing; Contour Analysis; Heart Movement; Long Time Monitoring; Acceleration Sensor; Biomedical Equipment

Introduction

By the invention of the stethoscope in 1816, "auscultation" became possible, introducing an exciting and practical new method of bedside examination (Ibrahim et al. 2002). Auscultation is performed for the purpose of examining circulatory system and respiratory system as well as gastrointestinal system, known as bowel sounds. It requires substantial clinical experience, a good listening skill. When many beginners first attempt to use a stethoscope in clinical settings to detect/diagnose diseases of the heart and the lungs, they often have difficulties hearing the characteristic sounds. In fact, the shared bands (frequency and sound pressure) between audible sounds and heart sounds are very narrow. Furthermore, heart sound through bifurcated tube of a stethoscope due to interference enhanced/attenuated of oscillating wave may be changed in an instant during the time of one heartbeat (0.75–1.2 s). Sound of the stethoscope is vibration of the air surrounded by the small chamber at the chest surface. Some reports on 3-D graphic techniques (Makino et al. 2004), using holographic interferometry (Hök et al. 1976) and data-recording apparatus (Karki et al. 2007, Nanda et al. 1986) have been seen; in clinical area , echocardiography is generally used to diagnose cardiovascular diseases; however it requires special equipment and another associated techniques (Okada et al. 1982, Verburg et al. 1983, Vermarien et al. 1989, Cozic et al. 1998, Arakawa et al. 1976). Meanwhile, we tried multichannel measurement and visualization of vibrational distribution of the chest surface using microphone and acceleration sensors (Nogata et al. 2009, 2010). This report presents a technique for visualizing vibrational distribution of chest's surface as quick and easy method. The visualized results showed typical events such as motion of the contour of heart wall by strong pressure shock due to closure of valves with pumping of blood to aorta. We expected that the technique would assist much better understanding of heart function visually.

Measurement Technique

A trial equipment for visualizing vibrational distribution of the chest surface is shown in Fig. 1. The device consists of 64-channel sensor unit, amplifier unit and A/D converter unit which were connected to a personal computer installed MATLAB software. The acceleration measurement unit consists

of “8x8” sensors fixed at intervals 20 mm (sixty three acceleration sensors with one ECG measurement) with reference to the mid-spinal line. The sensor was 6 mm in diameter (S12-M1S5B) and adhesive type ECG electrode were used respectively, and a couple of heartbeats were recorded. In preliminary experiment, the time of fixing sensors to the skin was needed 30 minutes approximately. Then a new soft mounting plate which embedded these sensors was developed. As a result, the total time of the installation and measurement became five minutes approximately. When recording heart sounds, the subject was asked to stop breathing activity for a couple of seconds. In an image process, sampling frequency of 3 kHz with quantization of 12 bits was performed. A new image with 256x256 pixels was reconstructed using the original image of 8x8 pixels by applying a cubic spline interpolation method.

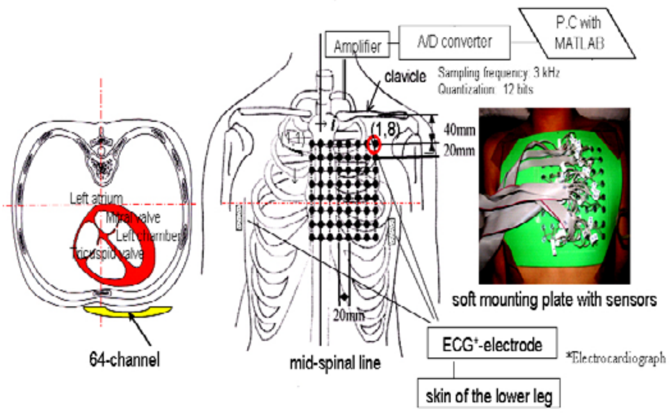

FIG. 1 MULTICHANNEL MEASUREMENT SYSTEM FOR VISUALIZING VIBRATIONAL DISTRIBUTION OF THE CHEST SURFACE USING A SOFT MOUNTING PLATE

Results And Discussion

The heart sounds are noises generated by tissues vibrations with cyclic motion of the heart and resultant flow of blood through the heart. In healthy adults, there are two normal heart sounds that occur in sequence with each heartbeat; these are the first heart sound (S1) and the second heart sound (S2). Ordinarily, the S1 is caused by the sudden blockage of reverse blood flow due to closure of the atrioventricular valves (mitral and tricuspid) at the beginning of ventricular contraction. The S2 is then caused by the sudden blockage of reverse blood flow due to closure of the aortic and pulmonary valves at the end of ventricular systole, i.e., the beginning of ventricular diastole. In addition to these normal sounds , other sounds may be present including cardiac murmurs, adventitious sounds, and gallop rhythm sounds, the S3 and S4. We discussed relation of ECG, heart sounds and vibration of the chest surface with characteristics of the heart motion mentioned above.

ECG signal, Heart Sound and Chest Vibration

Figure 2 shows sixty three signals of the chest's surface vibration and an ECG signal which connected the terminal pin number (1, 8); time of S1-1 is contraction of cardiac ventricle and becomes almost maximum pressure of the ventricular at S1-2 and S1-3, mitral and tricuspid valves are open at S1-4, S2-1, and then blood flows into the ventricle at S3. Using these data, distribution of the chest’s surface vibration is visualized.

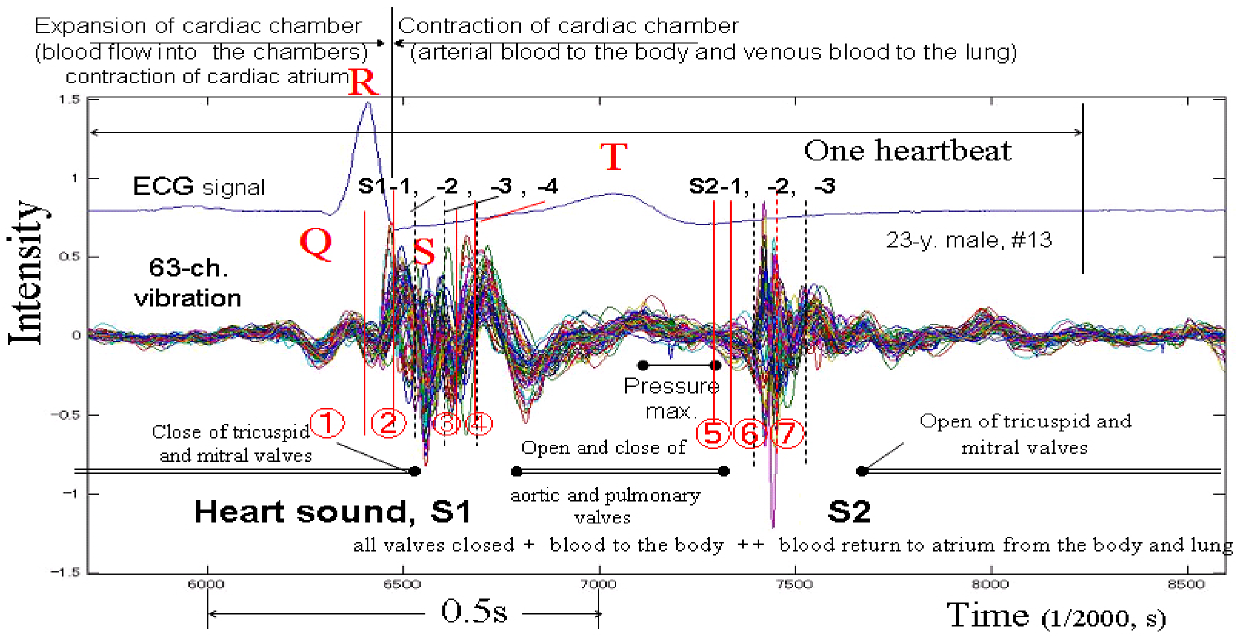

FIG. 2 TYPICAL RESULT OF 63-WAVE FORM OF THE CHEST VIBRATION AND ECG SIGNAL

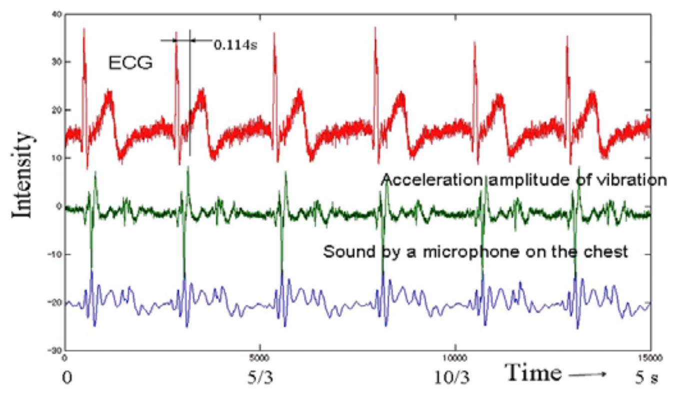

FIG. 3 TIME DIFFERENCE DELAYED FROM ECG SIGNAL AUSCULTATORY SOUND AND VIBRATION RECORDED AT THE APEX OF THE HEART, SENSOR No. (8-9)

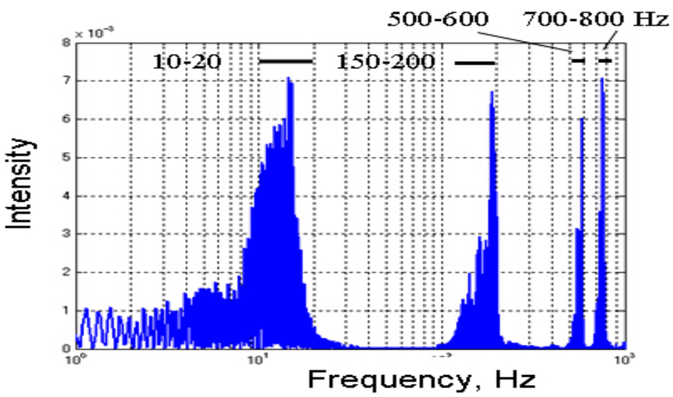

FIG. 4 FFT RESULT OF No. (5,6) SENSOR ON THE CHEST SURFACE

Figure 3 shows three signals (ECG, vibration of the chest and auscultatory sound by a microphone embedded in the tube of stethoscope) recorded at apex of the heart. From the graph, it was recognized that auscultatory sound and vibration data were 0.114 s delayed from the ECG signal (QRS). The time means difference between electric signal and movement of the heart that relates cardiac function because time of wave propagation in the body was ~0.03 ms (depth of the heart; ~50 mm, sound velocity; 1520 x 10^3 mm/s, i.e. 50/1500 x 10^3). Thus, these data allows inspecting cardiac function from viewpoint of movement. There was no delay time between vibration of chest surface and the sound, since auscultatory sound is vibration of the air surrounded by the small chamber at the chest surface.

Figure 4 shows a typical FFT-intensity graph of the terminal pin number (5-6), which has four frequency bands. These frequency depend on vibrations caused as the result of closures/opening of valves, blood flow and wall deformation due to heartbeat. It is noted that these include very low frequency that is inaudible sound (10–20 Hz). If the vibration includes any abnormal event of the heart motion, it will be difficult detection for clinician.

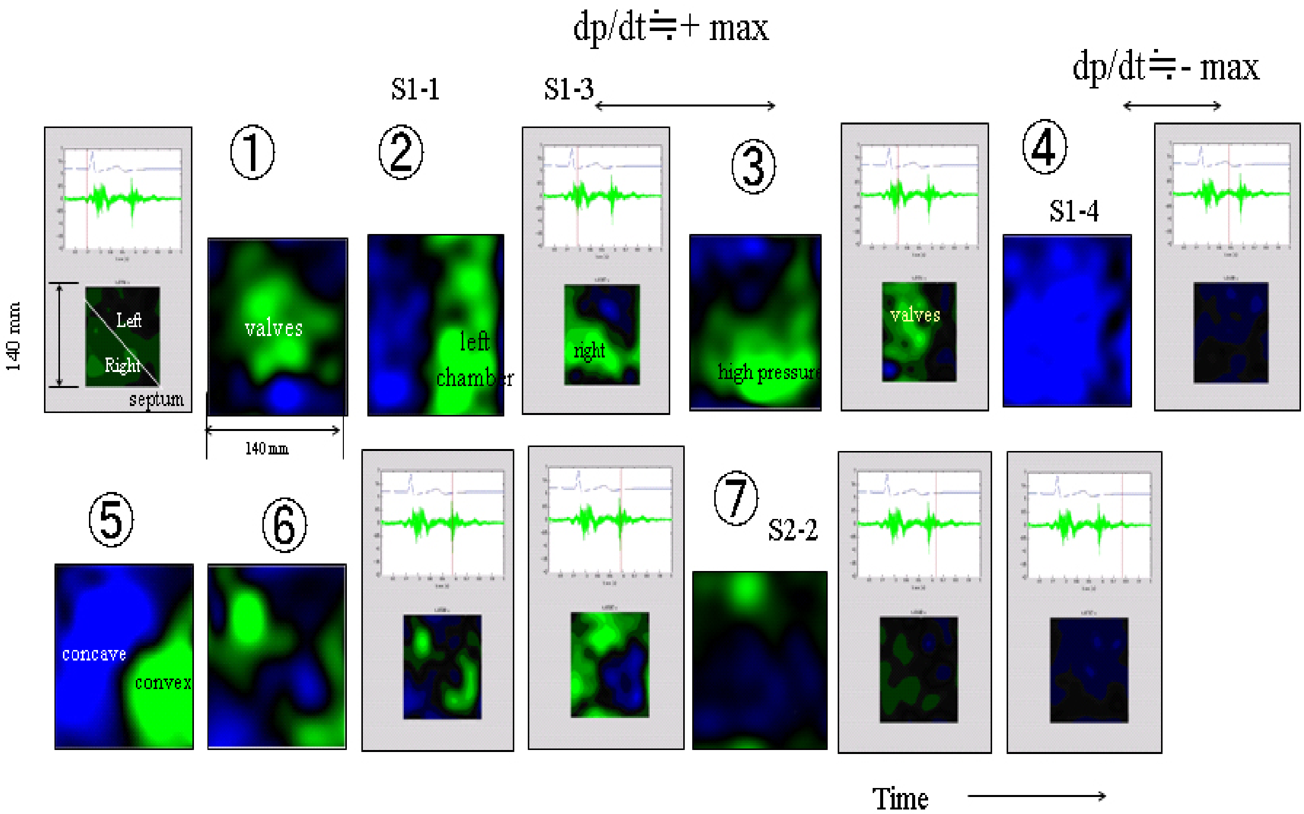

FIG. 5 GRAPHICAL CHANGES IN CHEST SURFACE VIBRATION WITH WHOLE FREQUENCY BAND; GREEN SHOWS CONVEX DIRECTION AND BLUE SHOWS CONCAVE DIRECTION OF THE CHEST SURFACE. BRIGHTNESS IS RATE OF INTENSITY

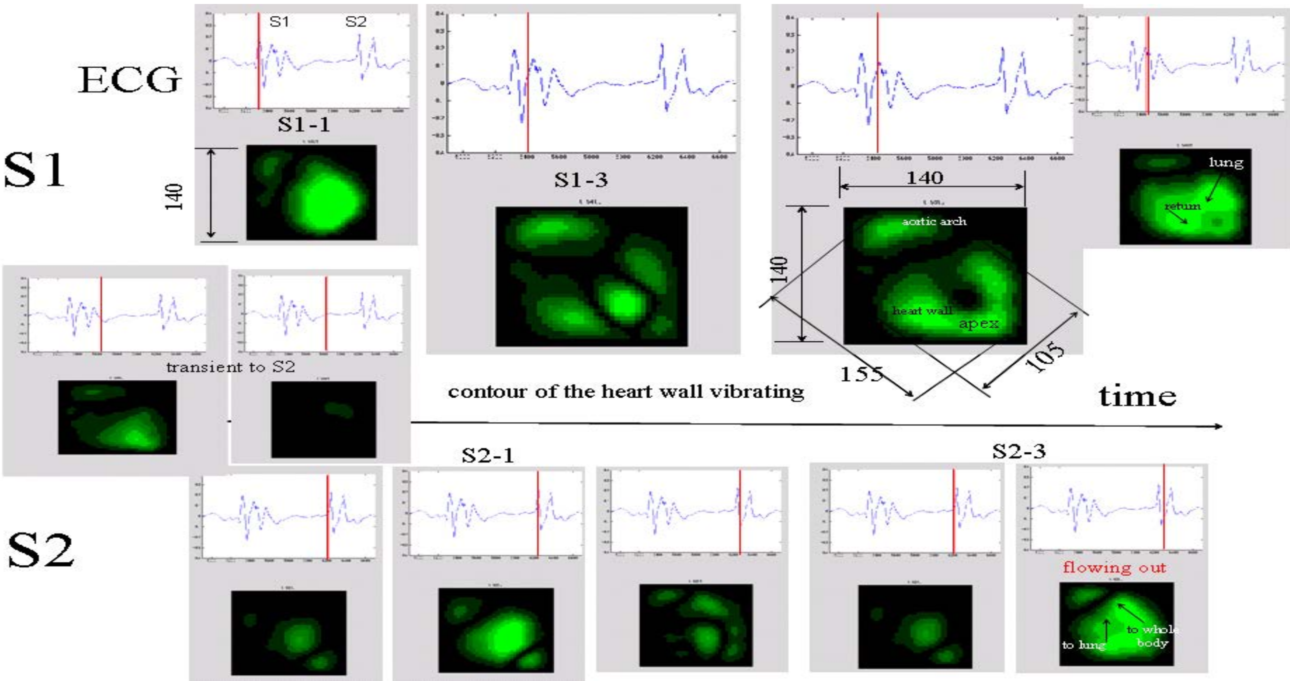

FIG. 6 GRAPHICAL CHANGES IN CHEST SURFACE VIBRATION WITH LESS THAN 50 Hz FREQUENCY BAND

Visualized Chest Surface Vibration

Figure 5 shows visualized heart motion frame-by-frame image by using all frequency data. It is noted that color of image means rate of acceleration of the chest's motion; green color is convex and blue color is concave direction of the chest surface. In each image, it has ECG signal graph as a reference time of heart motion.

From a series of image, we can recognize location of valves, convex/concave of right-and-left, cardiac chamber dilation/contraction, and atrium cordis. Therefore, images created by whole vibration data are tissues of rapid movements of the heart.

Figure 6 shows image created with less than 50 Hz range. It can be seen such as clear contour of the heart, slow movement of expanding/shrinking, and full blood in cardiac chamber at around the time of S1-4. From the image at time of S1-2, the width of the heart was 105 mm and the height including aortic arch was 155 mm approximately. By comparison with the image of ultrasonic cardiogram in Fig. 7, size of the heart and location of valves are equivalence result (110x125 mm). The technique is simple device and easy installation by using a new attachment, which providestwo thousand images per second (0.5 ms interval) for analysis. Therefore, it'll allow examining movement and function of the heart in detail. It can be concluded that vibrational distribution of the chest surface is informative for understanding heart function visually. The technique may also allow inspection of heart movement and its function for long-time monitoring without using echocardiography; e.g., monitoring heart motion in an operation and its after, analysis of abnormal heart rhythm, and heart motion state of mental tension and of symptom of apnea in sleep.

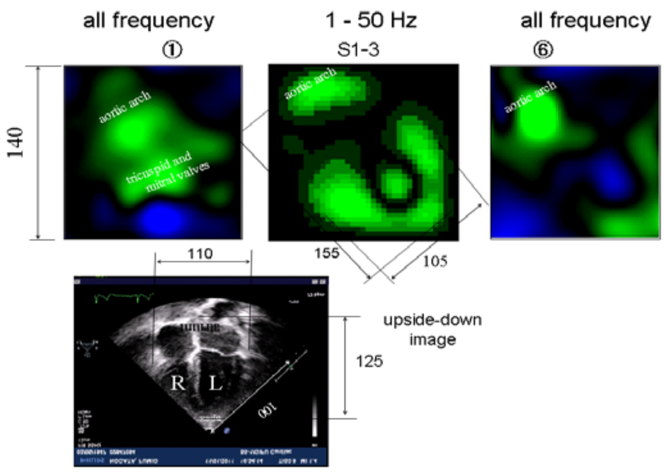

FIG. 7 COMPARISON OF ECHOCARDIOGRAPH AND CHEST VIBRATION IMAGES

Individuality and Reproducibility

We measured 18 subjects to establish techniques including image processing, development of a new mount plate and reproducibility depending on individuality. Figure 8 shows the image of individuality dependence at the time of closing tricuspid and mitral valve (S1-2) of four subjects. These are similar contour images due to mounting method of the sensor unit using the soft plate as

shown in Fig. 1. In this experiment, it is dependent on whether reproducibility is in agreement with contact pressure and the mid-spinal line..

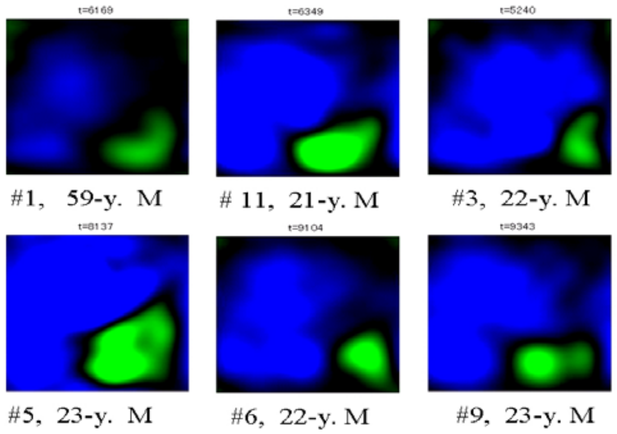

FIG. 8 DEPENDENCE OF INDIVIDUAL SUBJECTS AT TIME OF TRICUSPID AND MITRAL VALVE CLOSED, S1-2

Concluding Remarks

When placing a hand on the chest, we can feel vibration of heart beating. Thus, we tried visualization of the vibration from viewpoint of time and area, and developed a new measurement system using multichannel sensors. And availability of the system to use of biomedical inspecting function of the heart was discussed. It can be summarized as follows.

1) The technique is simple device and easy installation using a new attachment. Two thousand images per one second provided for analysis, which are informative to examine function of the heart. Frequency of the chest vibration has three or four bands as 10–20 Hz, 100–200 Hz, and 700–800 Hz.

2) By using vibration of the whole frequency band, images of strong intensity regions such as valves and changing of pressure were created. Meanwhile with less than 50Hz frequency band, images of macroscopic contour of heart's wall were created.

3) The technique may also allow inspection of heart movement and its function for long-time monitoring without using echocardiography; e.g., monitoring heart motion in an operation and its after, analysis of abnormal heart rhythm, and heart motion state of mental tension and of symptom of apnea in sleep.

To finalize the project as a practical use, clinical application and discussion about relationship between these images and heart motion/function are needed.

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Fumio Nogata received B.E. and M.E. from Kanto Gakuin University, and Dr. Engineering from Tohoku University. He was research assistant, lecturer, and associate professor at the Dep. of Mechanical Engineering of Himeji Institute of Technology, Hyogo from 1974. He stayed at the Dep. of Biology, University of York (UK) in 1990 as a visiting researcher for one year. In 1998, he joined Gifu University, and an emeritus professor from 2012. His main interests are bioinstrumentation, biomechanics and its application.

Yasunari Yokota was born in Tokyo, Japan, on March 6, 1967. He received B.S., M.S., and Dr. Eng. degrees in Information Science from Toyohashi University of Technology, Toyohashi, Japan, respectively, in 1989, 1991, and 1994. During 1994-1996, he was a Research Associate at Nagoya Institute of Technology, Nagoya, Japan. During 1996-2010, he was an Associate Professor at Gifu University, Gifu, Japan. Since 2010, he has been a Professor at Gifu University, Gifu, Japan. His interests are in signal and image processing, information theory, and their applications to biological signal analysis. He is a member of IEEE, SICE, and JSMBE.

Yoko Kawamura received the B.E., M.E. and Dr. Eng. degrees in Electronics and Information System Engineering from Gifu University, Japan, respectively, in 1998, 2000, and 2006. During 2006-2011, she was at the Department of Human & Information Systems and the Department of Information Science, Gifu University, as a postdoctoral fellow. Since 2012, she has been a postdoctoral fellow, Research and Development Center for Human Medical Engineering, Gifu University. Her research interests include bioengineering and medical imaging. She is a member of IEE, IEICE, JSMBE and JSICM.